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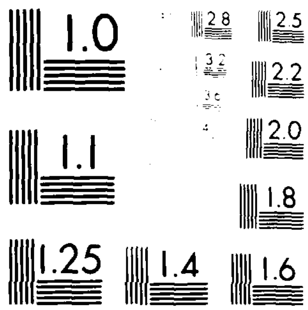

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AD-A144 861

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US Army Corps of Engineers

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Conductive backfill for improving electrical grounding in frozen soils

P.V. Sellmann, A.J. Delaney and S.A. Arcone

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This report is an extension of the authors' earlier resistance-to-ground experiments. Here they supply additional information on the influence of salt-treated backfills around grounding electrodes for reducing resistance to ground. The results are based on observations made over several seasons of freezing and thawing at sites selected for their variations in grain size, ice content, and ground temperature. More than 20 test electrodes were monitored at two silt sites and one alluvial site. The diameter of the backfilled zones, the salt content, and the backfill material were varied for the electrode

20. Abstract (cont'd)

installations. In all cases salt backfilling reduced the resistance to ground, with 175 ohms being the lowest value obtained. Reductions varied from very small to an order of magnitude. Resistance also decreased over several seasons. Generally the greatest improvement and lowest values were obtained in the perennially frozen silt in interior Alaska. Data from colder silt suggest that salt backfilling will not be effective in arctic settings. Measurements at a partially thawed, coarse-grained site indicate that salt was moving much more rapidly (approximately five times as fast) away from the treated backfill than at the silt site in the CRREL permafrost tunnel.

PREFACE

This report was prepared by Paul V. Sellmann, Geologist, of the Geotechnical Research Branch, Experimental Engineering Division; Allan J. Delaney, Physical Science Technician, of the Snow and Ice Branch, Research Division; and Dr. Steven A. Arcone, Geophysicist, also of the Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this study was provided by DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Task D, Cold Regions Base Support: Design and Construction, Work Unit 001, Electromagnetic Geophysical Methods for Rapid Subsurface Exploration. This report was technically reviewed by Ronald Atkins and Donald Haynes.

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CONDUCTIVE BACKFILL FOR IMPROVING ELECTRICAL GROUNDING IN FROZEN SOILS

Paul V. Sellmann, Allan J. Delaney and Steven A. Arcone

INTRODUCTION

High electrical resistance of grounding sites is common in areas where the ground freezes. However, the performance of grounding installations can often be increased through site selection and various electrode installation schemes (Hessler and Franzke 1957, Nozhevnikov 1959, U.S. Army Engineer District, Alaska 1973, Sellmann et al. 1974). The degree of improvement will depend on the local existence and accessibility of conductive soils. The most common conductive sites are associated with thaw zones or clay-rich soils. The greatest grounding problems usually occur where bedrock, coarse-grained soil, or cold, ice-rich soil is found near the surface.

In temperate regions, small field installations can usually be adequately grounded by driving a simple vertical electrode into the soil. This technique has been unsuccessful in areas of frozen ground because: 1) driving electrodes is difficult, 2) frozen materials tend to be electrically resistive, and 3) high contact potentials can develop between a rod and the frozen soil because a thin ice layer can form around the cold rod.

Installation procedures can be modified in some frozen ground settings to eliminate some of these problems, permitting order-of-magnitude reductions in the resistance to ground. However, in many regions of the Arctic, electrical resistivity of the frozen ground is extremely high, and grounding will not be significantly improved by local modification or treatment of the soil surrounding the electrode. Achieving "low" resistance grounds of less than several hundred ohms will often require that the site be selected in a zone of conductive material, as may be concluded from the modeling studies done by Arcone (1977).

In a previous study (Delaney et al. 1982) we evaluated the use of shaped charges for ground rod emplacement. The following questions were raised by that work:

1) What is the influence of ground temperature, material type and associated variations in unfrozen water content on the performance of an installation?

2) What is the influence of material type and associated differences in permeability and saturation on salt solutions added to the soil surrounding an electrode?

3) What is the effectiveness of using more than one electrode for lowering resistance to ground?

4) What is the long-term influence of conductive backfills and what is the suitability of various materials for backfill around electrodes placed in holes of larger diameter than the electrodes?

The objective of this project was to evaluate techniques designed for rapidly improving electrical grounds in frozen soils at temporary field sites or for military operations. The main procedure investigated was to place electrodes in open holes having diameters greater than the electrodes, making emplacement easier and permitting the use of conductive backfill. The holes were made by drilling or blasting with shaped charges. Observations of ground performance were made through periods of seasonal freezing and thaw. In a more limited study we also investigated an array of horizontal rods driven into the active layer.

INSTALLATION AND MEASUREMENT METHODS

Electrode installation

Holes were drilled with augers designed for use in frozen ground. Hole diameters ranged from 3.8 to 91.4 cm, with depths seldom greater than 2 m. Hand-held equipment, consisting of an electric drive and a 5-h.p. gasoline-powered drill (Little Beaver), was used for most of the shallow, smaller-diameter holes. Both units could be used with a coring auger to drill holes up to 11 cm in diameter in fine-grained frozen soils. A truck- mounted auger (Williams HD-50) was used for the larger-diameter vertical holes drilled in coarse-grained materials. The horizontal electrodes were hand-pushed and then driven into the thin seasonally thawed layer.

Military 6.8-kg (M2A3) shaped charges were also used to produce vertical holes. Their similar performances in a range of frozen materials, with penetration approaching the length of standard electrodes, made this charge size ideal for electrode installation, as previously reported by Delaney et al. (1982) and Mellor and Sellmann (1970). The volume of several of the drilled holes was also expanded by using C-4 block explosives.

Backfill

Reduction of contact potential is important in establishing a good electrical ground. In frozen soil, ice can form around the electrode,causing high contact resistance. Ice formation on the rod surface is likely since the rod is easily chilled by exposure of the upper end to low air temperatures. The beneficial effect of pouring untreated water around an electrode will only be very short-term in cold environments. Therefore, the use of conductive backfill with a low freezing point was evaluated.

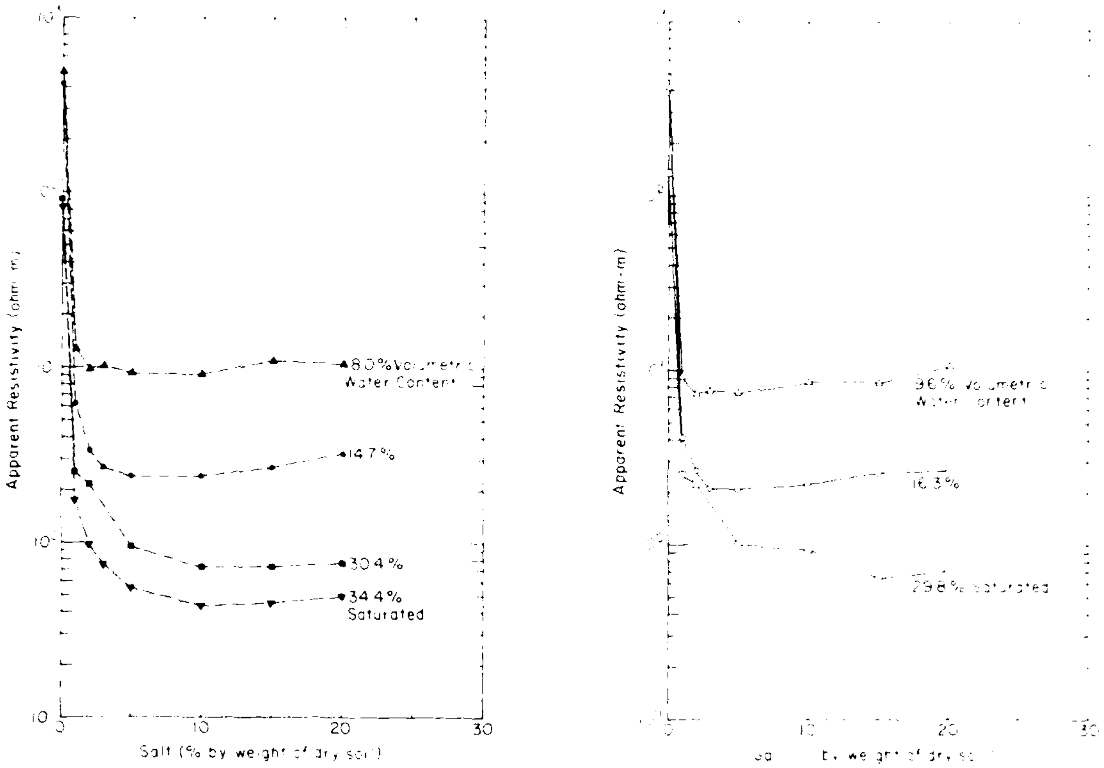
The backfill was prepared by mixing salt and local soil or by saturating the soil backfill with a salt-water solution. Backfill other than soil was also used because soil is not always easily recovered from some drilled or blasted holes and because unfrozen material is difficult to find during the winter. Absorbent paper saturated with a salt solution and compacted in the hole around the electrode was evaluated as a soil substitute in several installations.

The amount of salt added to the backfill was determined by preliminary laboratory conductivity measurements of several salt-soil mixtures. Salt was added to Fairbanks silt and to a fine sand to obtain mixtures of from 0 to 20% salt based on the weight of the air-dried soil. Distilled water was added to the salt-soil mixtures to obtain several soil moisture levels up to saturation for both materials. The soils were compacted into a cylindrical plexiglass ring, which was clamped between electrodes for resistivity measurements at 1 kHz. Figure 1 shows the resistivity for two soils as a function of salt concentration at several volumetric moisture contents. A salt-soil mixture containing 1% salt results in a dramatic decrease in resistivity, with little effect after 5% salt for most moisture levels. Therefore, we chose 5% salt by weight for backfill as it produces a very conductive salt-soil mixture with the least amount of salt.

Salt solution was also poured around shallow-driven horizontal electrodes to minimize contact resistance during freezeback. Salt solutions in general had concentrations on the order of 50-100 $^{o}/oo$.

Measuring electrode resistance

The fall-of-potential method described by Tagg (1964) was used to measure the electrode resistance in these studies. In Figure 2 electrode E is being tested and is one element of a three-electrode array. A known current I is passed between electrodes E and C. Electrode C is a fixed distance from



a. Fairbanks silt.

b. Fine sand.

Figure 1. Apparent resistivity for two soils at various moisture and salt contents.

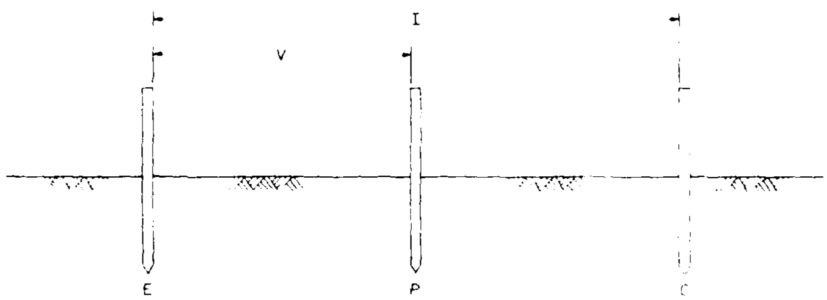


Figure 2. Electrode configuration used to determine the resistance to ground.

E, great enough to remove C from the influence of E. The induced voltage V between electrodes E and P is then measured as electrode P is moved along the line E-C. The resistance to ground of electrode E is the ratio V/I at the P-E separation where the influence of electrodes upon each other is negligible. Therefore, V/I is simply plotted as a function of the distance P-E, and the resistance to ground is the value of V/I in the central, flat portion of the curve. For a single vertical electrode the "true" resistance is theoretically obtained when the distance P-E equals 61.8% of the distance E-C.

A low frequency a.c. signal was used for a current source to avoid polarization at the soil/electrode interface. Voltage measurements were made with a high-input impedance meter, which is extremely important in high-resistance soils.

In theory (Tagg 1964) the resistance to ground R of a single vertical electrode of length ℓ and radius α, emplaced in homogeneous soil of resistivity ρ (ohm-cm), is found from

$$R(\text{ohms}) = \frac{\rho}{2\pi\ell}\left[\ln\frac{4\ell}{\alpha} - 1\right]. \qquad (1)$$

This equation was used to estimate the penetration depth of conductive salt solutions in the soil adjacent to the treated backfill. Since the backfill is conductive, the electrode radius is not that of the metallic electrode, but initially the diameter of the hole filled with treated backfill. This large composite electrode is referred to as the effective electrode. For a constant ground temperature, any reduction in electrode resistance of a frozen saturated soil with time should be related to an increase in effective electrode diameter, presumably through salt movement. This increase was determined as follows. First the soil resistivity ρ was calculated from eq 1 using the resistance to ground of a test electrode and the effective electrode radius measured at the time of installation. A year after installation the resistance to ground was remeasured, and the effective electrode radius was calculated from the following form of eq 1, using the soil resistivity calculated earlier:

$$\alpha(\text{cm}) = \frac{4\ell}{\exp[1 + (2\pi\ell R/\rho)]}. \qquad (2)$$

Table I. Electrode characteristics and resistance to ground.

Installation Date	Location	Material	Installation technique	Backfill	Depth (m)	Rod dia (cm)	Hole dia (cm)	Resistance to Ground (ohms) Sep 80	Apr 81	Apr 82	Apr 83	Jul 83
Sept 80	Elelson-1	Silt	Driven	None	0.6	1.6	--	1200	1500			1350
	Elelson-2	Silt	6.8-kg shaped charge	Silt/water	1.9	1.6	7.6	235		1700	740	180
	Elelson-3	Silt	6.8-kg shaped charge	2.2 kg salt/silt/water	1.4	1.6	10.2	190		205	300	152
	Elelson-4	Silt	6.8-kg shaped charge	4.5 kg salt/silt/water	1.9	1.6	7.6	145	380	580	175	120
July 83	Elelson-5	Silt	Augered hole/ 0.57-kg C4	26 L salty water	1.37	1.6	11.0					350
	Elelson-6	Silt	Augered hole/ 1.13-kg C4	79 L salty water	1.70	1.6	11.0					325
	Elelson-7	Silt	Augered hole/ 1.7-kg C4	79 L salty water	1.67	1.6	11.0					250
	Elelson-8	Organic mat	1 horizontal rod*	10 L salty water poured on the active		1.6	None					335
	Elelson-8a	Organic mat	2 horizontal rods*	layer surface along each rod		1.6	None					230
	Elelson-8b	Organic mat	3 horizontal rods*			1.6	None					195
	Elelson-8c	Organic mat	4 horizontal rods*			1.6	None					175
Apr 82	Wainwright-1	Sand	Augered hole	Soil	1.52	1.9	12.7			6800	4500	460
	Wainwright-2	Sand	Augered hole	2.2 kg salt/paper/ soil/water/	1.83	1.9	12.7			3900	950	590
	Wainwright-3	Sand	Augered hole	0.91 kg salt/paper/ soil/water	1.83	1.9	12.7			7500	1750	870
Apr 83	Wainwright-4	Sand	Augered hole	29 kg salt/sand	1.9	1.6	76.2				1150	260
	Wainwright-5	Silty sand	Augered hole	19 kg salt/sand	1.78	1.6	61.0				2450	350
	Wainwright-6	Silty sand	Augered hole	10 kg salt/sand	1.83	1.6	30.5				2000	680
	Wainwright-7	Sandy silt	Augered hole	3.6 kg salt/sand	1.88	1.6	20.3				1080	850
Apr 82	Tunnel	Silt	Driven	None	0.6	1.6	--			7000	6700	
	Tunnel-1	Silt	Augered hole	2.1 kg salt/paper/water	0.86	1.6	11.3			4000	2800	
	Tunnel-2	Silt	Augered hole	2.3 kg salt/silt/water	0.86	1.6	11.0			8500	4500	
	Tunnel-3	Silt	Augered hole	0.46 kg salt/silt/water	1.14	1.6	3.8			7500	4700	

*Rods (2.44 m long) inserted in the unfrozen active layer (50-75 cm thick).

RESULTS

Three field sites were investigated in interior Alaska. These sites vary in material type, amount of frozen ground, and soil temperature. The results of observations at the sites, along with information on each installation, are summarized in Table 1.

Site 1

Test site 1 (called Eielson) is located on a northwest-facing hillside in a remote section of the Ft. Wainwright military reservation near Eielson Air Force Base. The area is covered by a dense forest of black spruce and birch, with an organic layer that seasonally thaws down to about 70 cm. The mean annual air temperature is -3.2°C (U.S. Weather Bureau 1943). This site is typical of the permafrost terrain found in central Alaska's extensive upland region, which extends from Fairbanks to well north of the Yukon River. The perennially frozen soil at this site is ice-rich silt or organic silt (Williams et al. 1959, Sellmann 1967). In this area permafrost just below the active layer typically has temperatures a few tenths of a degree below 0°C in mid-September and about -2°C in mid-April. The silt below the active layer has very low organic content.

This site was used for our initial experiment to evaluate the influence of salt-treated backfill. The electrodes were installed in an expedient manner to simulate a military installation. The first grounding electode (Eielson 1) was driven to refusal and is a reference electrode, simulating a conventional field installation. The rod diameter was 1.6 cm,and the total installed depth into the frozen ground was 60 cm. No conductive additive or backfill was used. The data for this electrode are shown in Figure 3 and Table 1, with variations reflecting the accuracy of the measurement technique and seasonal changes in electrical properties. The true resistance to ground at the time of installation (fall 1980) was 1200 ohms. The active layer was thawed at this time, and winter observations were simulated by removing the thawed material around the electrodes. In April 1981, when

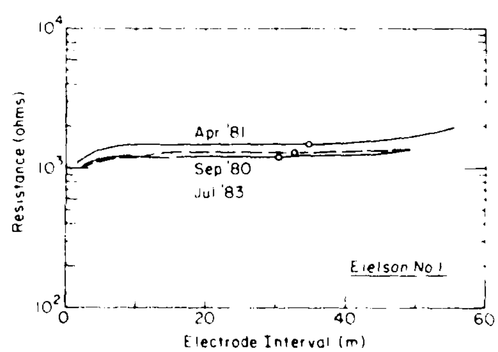


Figure 3. Resistance-to-ground curves for an electrode driven into ice-rich silt (Eielson 1).

the active layer was frozen, the resistance was 1500 ohms. Nearly three years after the installation the resistance during the thaw period was measured at 1350 ohms after the thawed conductive material was removed from around the upper part of the electrode.

The resistance of this driven electrode was used for comparison with other test electrodes at this site (Delaney et al. 1982). The first test electrodes were installed in holes produced by using 6.8-kg military shaped charges to demonstrate their application for rapid emplacement of vertical grounding rods. The holes were then backfilled with 1) saturated silt, 2) silt, water and 2.27 kg of salt, and 3) silt, water and 4.5 kg of salt. The salt was mixed with the soil during backfilling.

Eielson 2 was a vertical grounding rod in a 1.9-m-deep hole backfilled only with saturated silt (Fig. 4). This electrode had a true resistance of 235 ohms at the time of installation. After one winter the resistance increased to 1700 ohms -- very close to the value of the reference electrode. Hence, there was no advantage to increasing the installation depth of a single vertical rod in frozen silt if backfilling is done only with saturated soil, unless the installation could be used before the water saturated soil froze. Increased thaw around the electrode may explain the lower resistance values obtained during the spring of 1983.

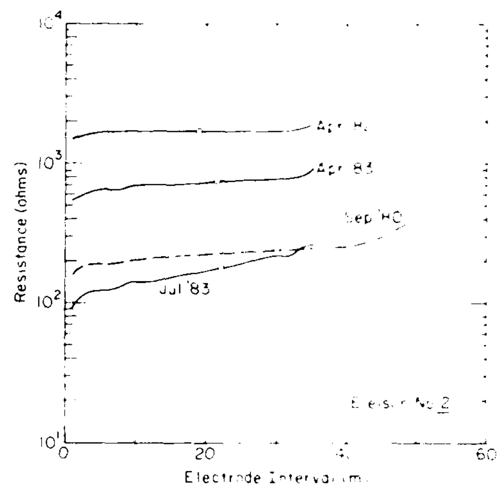


Figure 4. Resistance-to-ground curves for an electrode surrounded by a backfill of saturated silt (Eielson 2).

Eielson 3 was an electrode placed in a 1.4-m-deep hole backfilled with 2.27 kg salt, silt and water (Fig. 5). Initially the true resistance was 190 ohms; after three years it was 152 ohms. In this case the salt-soil back-

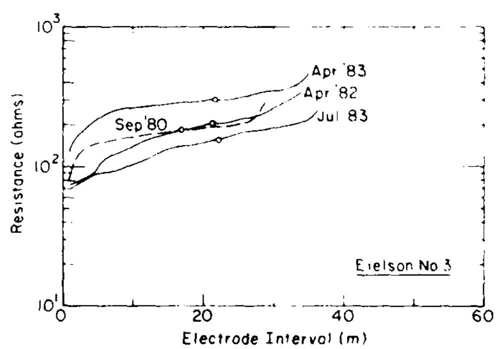


Figure 5. Resistance-to-ground curves for an electrode surrounded by a water-saturated salt-soil backfill (Eielson 3).

fill maintained a conductive unfrozen zone around the electrode throughout the year, with some indication of reduced resistance with time. This reduction may indicate salt diffusion into the surrounding silt, creating a larger unfrozen zone. The possibility and rate of salt movement is discussed later.

This installation demonstrates the effective use of conductive backfill for maintaining a ground at a low resistance. The scatter in the measured true resistance to ground for several seasons may reflect changes in the moisture content of the active layer.

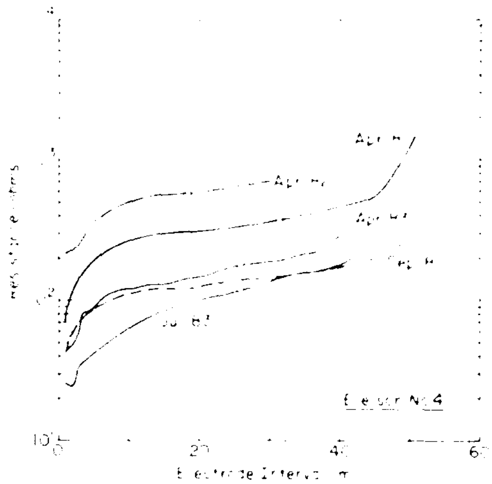
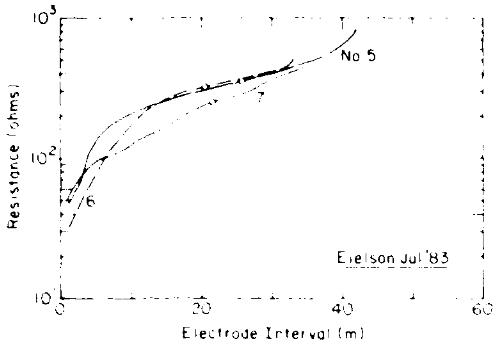


Figure 6. Resistance-to-ground curves for an electrode surrounded by a water-saturated salt-soil backfill (Eielson 4).

Eielson 4 was an electrode installed in a 1.9 m-deep hole backfilled with 4.55 kg of salt, silt and water (Fig. 6). There is more variation in the true resistance to ground than for the previous test electrode. Resistance at the time of installation was 145 ohms, decreasing to 120 ohms during the summer of 1983. The initial resistance of this installation was lower than both the rod backfilled with silt and the rod backfilled with 2.27 kg of salt. The higher April 1981 and April 1982 readings are unexplained.

In July 1983 three new modified grounds (Eielson 5, 6, 7) were installed at this location to determine if increased hole volume produced by an explosive charge in a drilled hole would significantly lower the resistance to ground and if any long-term benefits may be derived as salt moves into possible fractures. Three holes 11.0 cm in diameter, ranging in depth from 1.37 to 1.70 m, were drilled in the frozen silt with a modified CRREL coring auger using the Little Beaver portable power unit. An attempt to increase the contact area of these holes was then made using explosives. The influence of charge weight was determined using charges of 0.57, 1.13 and 1.70 kg, which increased the hole volume by approximately 0.01, 0.05 and 0.06 m^3, respectively. This corresponds with observations in similar material made by Mellor (1972), who reported increases of approximately 1 ft^3/lb (0.061 m^3/kg) of explosives.



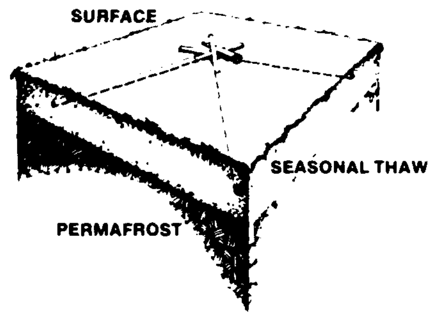


Figure 7. Resistance-to-ground curves for electrodes placed in holes modified by spring charges and filled with a salt-water solution (Eielson 5-7).

Figure 8. Configuration of nearly horizontal electrodes placed in the thawed active layer.

Copper-clad steel ground rods were inserted into these holes and backfilled with salt water. Salt water alone was used initially to determine the increases in hole volume as well as to provide a conductive link between the electrode and the fractured frozen soil. The salt solution was retained in the lower part of the hole because the frozen silt was impermeable. Soil backfill would also be required for a more permanent installation to assure good electrode contact in case some of the salt solution should drain. Figure 7 shows the resistivity plots for these installations. The true resistance to ground varied from 250 to 350 ohms. These values are comparable to those previously discussed. Fractures in the upper part of the holes allowed drainage and prevented the hole from being filled with the conductive solution. Therefore, a conductive path to the fractures could not be maintained, and their value as a means of reducing resistance to ground could not be determined.

In a separate experiment at Eielson, horizontal rods were manually inserted into the upper 50 cm of the unfrozen active layer (Eielson 8,8a-c) to determine if an improved electrical ground could be established in permafrost terrain during the period of surface thaw, without the use of additional equipment. The configuration of the installations is shown in Figure 8. The active layer thickness varied from 50 to 75 cm. Approximately 10 L of salt water was poured onto the tundra surface along each rod. A resistivity profile was then obtained for one-, two-, three- and four-rod arrays, with the rods connected at the center of a radial installation (Fig. 9). The true resistance varied from 335 ohms for one rod to 175 ohms for a four-rod array.

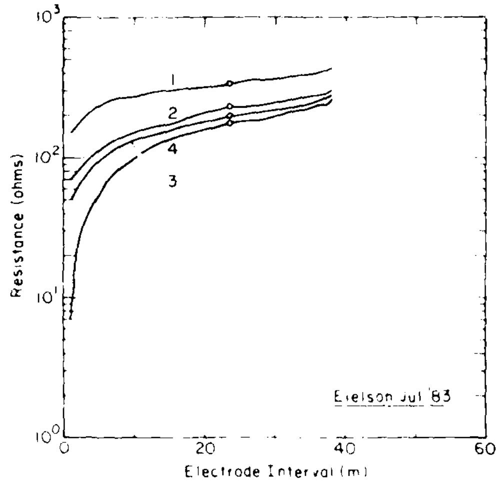


Figure 9. Resistance-to-ground curves for single horizontal and composite horizontal electrodes in a thawed active layer (Eielson 8, 8a-c).

This multi-rod horizontal technique provided values as low as might be expected for this location on the basis of minimum apparent resistivity values when the active layer is unfrozen. The method may be applicable to winter installations if a large quantity of salty water is used and a permeable organic surface mat exists.

Site 2

Test site 2, named Wainwright, is located adjacent to the Chena River on Ft. Wainwright in Fairbanks. This area consists of stream-deposited material, which is locally frozen and has a low ice content. Extensive deposits of this type occur throughout the expansive Tanana River flood plain. The site was selected to determine the effect of conductive backfills in permeable materials and to provide a contrast to the observations made in frozen silt. The top layer, approximately 0.7 m thick, is seasonally frozen sandy silt. An intermediate section, apparently unfrozen and extremely dry, ranges in thickness from 0.3 to 0.6 m. Below this dry zone is perennially frozen sand and gravel. The materials and their distribution were similar in each hole.

The first electrode installations (Wainwright 1, 2, 3) were made in April 1982. A rotary drill using compressed air for circulation was used to drill 13-cm-diameter holes to a depth of 1.5-1.8 m in order to simulate expedient field installations. A reference electrode (Wainwright 1) was back-

filled with compacted native soil without salt or additional water. Freeze-back would be required before it would simulate a driven electrode. The backfill for the second electrode (Wainwright 2) utilized 2.2 kg of salt, sand, highly absorbent paper and water to produce a thick slurry. The hole was then backfilled by interlayering several inches of the slurry with several inches of the sandy alluvium; water was added continually to assure saturation. For the third electrode (Wainwright 3), paper was mixed directly in the hole along with the sand, water and 0.91 kg of salt.

Resistance-to-ground measurements were made immediately after the electrodes were installed before any appreciable amount of salt could move into the adjacent soil (Figs. 10-12). Figure 10 shows the reference electrode to have varied from a winter high of 6800 ohms to a summer low of 460 ohms, for the most part due to seasonal thaw. One year after installation, electrode 2 (Fig. 11), containing the most salt, gave a winter value of about 950 ohms, and electrode

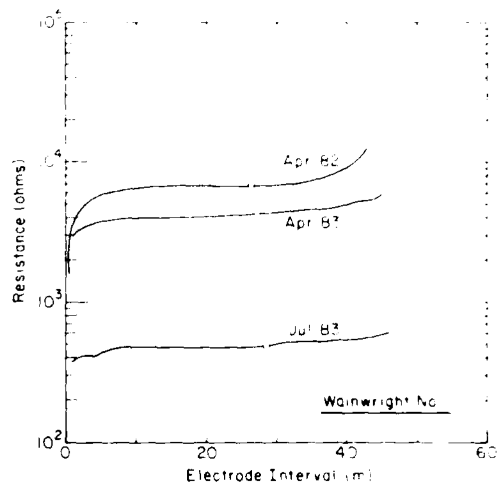


Figure 10. Resistance-to-ground curves for an electrode surrounded by a backfill of soil (Wainwright 1).

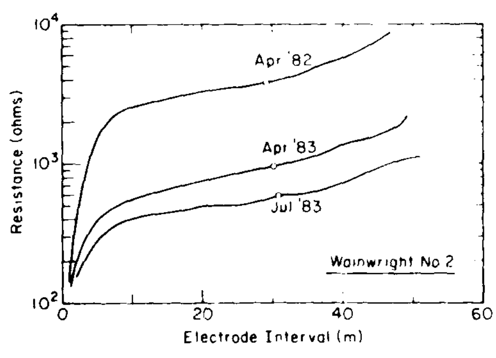


Figure 11. Resistance-to-ground curves for an electrode surrounded by a water-saturated salt-paper-soil backfill (Wainwright 2).

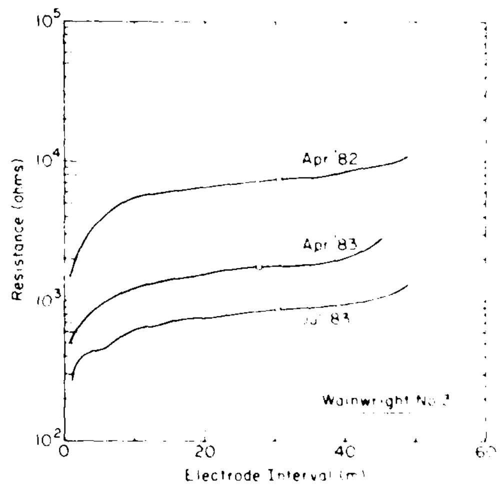


Figure 12. Resistance-to-ground curves for an electrode surrounded by a water-saturated salt-paper-soil backfill (Wainwright 3).

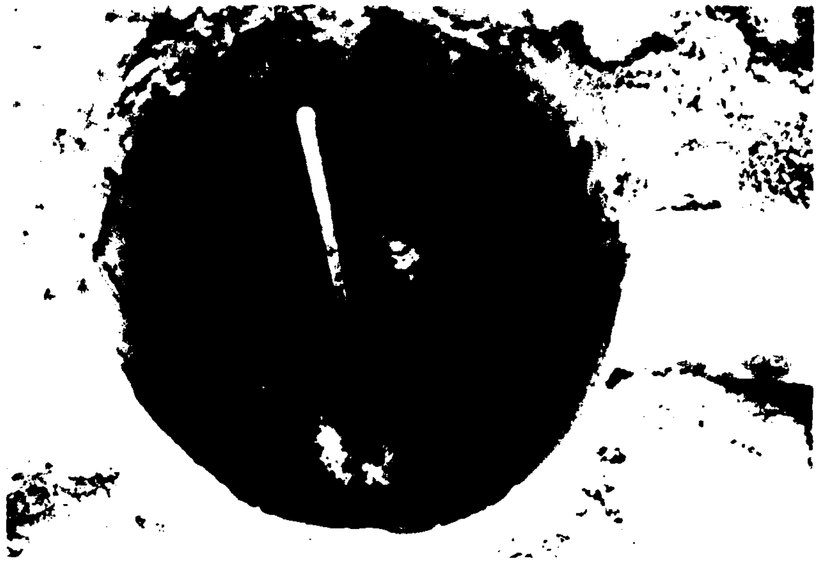


Figure 13. Installation of an electrode during the process of backfilling with a salt-soil mixture.

3 (Fig. 12) gave a value of 1750 ohms. This represents approximately an 80% decrease from the reference electrode for electrode 2 during the second winter.

Four additional electrodes (Wainwright 4-7) were installed to a depth of 1.8-1.9 m at this site in April 1983 using a large truck-mounted auger. The diameters were approximately 76, 61, 31 and 20 cm (Table 1), with 29, 19, 10 and 3.6 kg of salt used, respectively. These amounts represented approximately 5% by weight of the soil backfill, allowing us to vary the hole diameter while keeping the depth and backfill composition constant. The backfill mixture was periodically compacted during the backfilling process. An electrode installation during backfilling is shown in Figure 13.

The resistance of each ground was measured at the time of installation and again in July 1983. The July data are more reliable because of the time needed for ground and surface water to equilibrate. Data for each electrode are shown in Figures 14-17. In all cases the July values are lower than those measured at the time of installation three months earlier. The lowest resistance occurred at electrode 4, which had the largest diameter hole; the resistance to ground dropped from 1150 to 260 ohms. The greatest reduction occurred at electrode 5, where the resistance dropped by 2100 ohms. Variations between values calculated for all electrodes were probably influenced

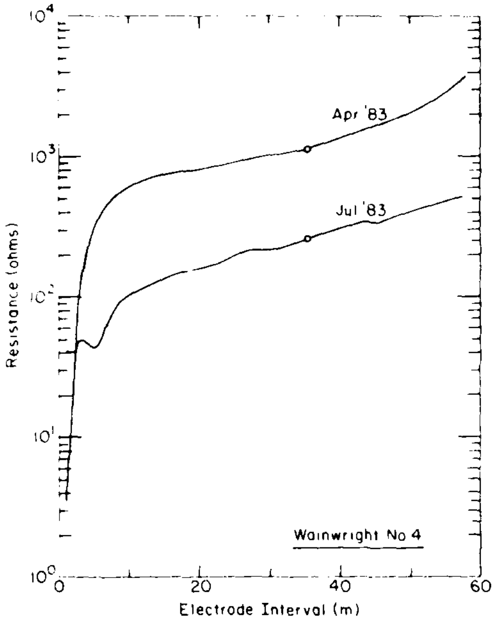


Figure 14. Resistance-to-ground curves for an electrode surrounded with conductive backfill in a 76.2-cm-diameter hole (Wainwright 4).

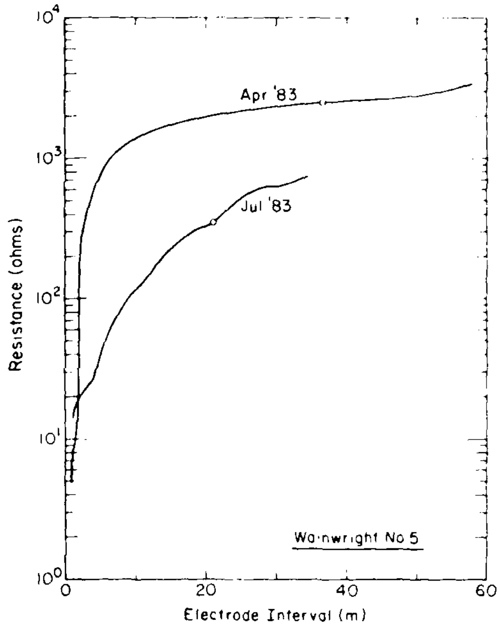


Figure 15. Resistance-to-ground curves for an electrode surrounded with conductive backfill in a 16-cm-diameter hole (Wainwright 5).

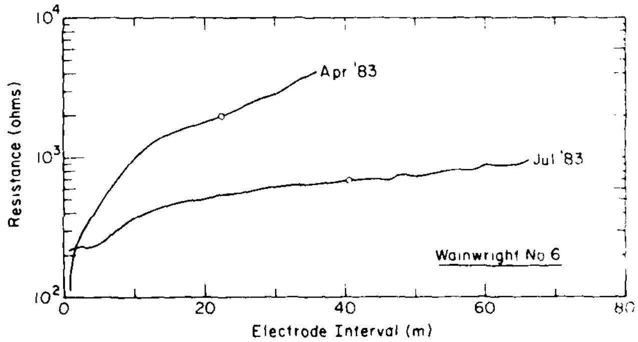


Figure 16. Resistance-to-ground curves for an electrode surrounded with conductive backfill in a 30-cm-diameter hole (Wainwright 6).

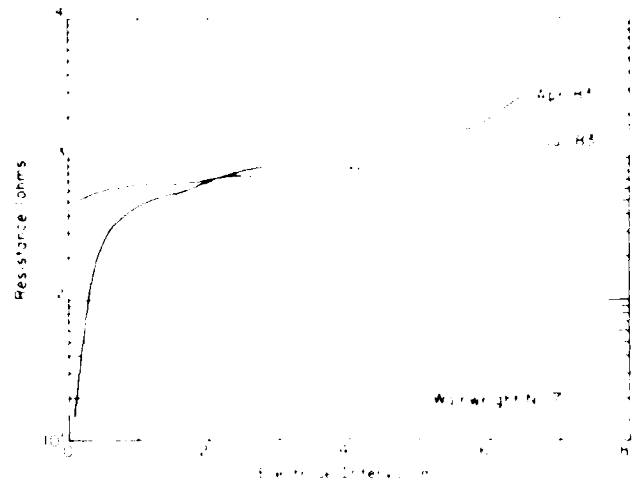


Figure 17. Resistance-to-ground curves for an electrode surrounded with conductive backfill in a 20.3-cm-diameter hole (Wainwright 7).

by the amount of frozen material surrounding the electrode and by fluctuations in the groundwater table with time and location.

Site 3

Test site 3, named tunnel, is located in the permafrost tunnel at Fox, Alaska, at a location where the materials were predominantly ice-rich silt (Sellmann 1967). This site is ideal for observing the influence of a salt-treated backfill with time, since large temperature variations and variations in the thickness of the thaw layer do not occur. The lack of thawed material in the tunnel makes interpretation of results much less complicated and permits consistant observations any time of the year. During winter the tunnel is cooled by circulating outside air. This results in tunnel soil temperatures that are lower than normally encountered in interior Alaska; the tunnel provides an accessible site for measuring the effects of cold permafrost on the performance of electrical grounds. The temperature was estimated to be -7° to -10°C at the time of the observation. Properties of the ice-rich silt were not determined at the time of the study. However, Sellmann (1967) has shown ground ice volumes in the silt to range from 53 to 80%. Indirect measurement of salt movement rates were deduced from the resistance measurements using the electrode installations.

A CRREL coring auger powered by a hand-held electric drive was used to produce a hole approximately 11 cm in diameter for backfilling and electrode

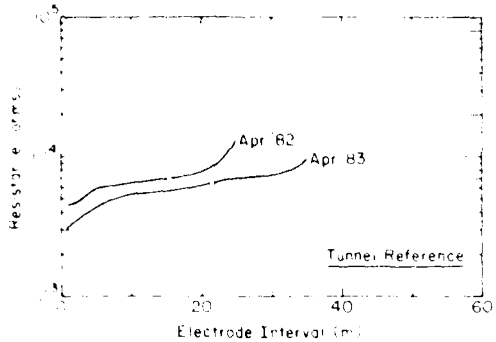


Figure 18. Resistance-to-ground curves for the driven reference electrode in the permafrost tunnel.

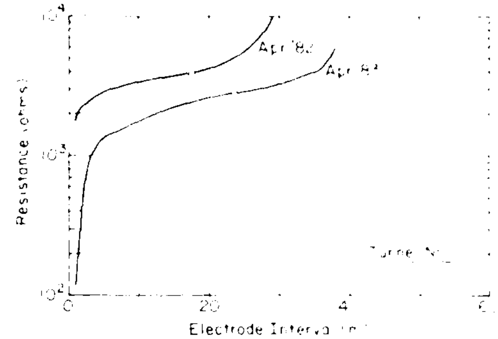


Figure 19. Resistance-to-ground curves for an electrode surrounded with backfill including salt (2.1 kg), organic material and water (Tunnel 1).

installation. In the cold, ice-rich silt at the tunnel, shallow (5-7 cm) holes 2.5 cm in diameter were drilled for the P electrode placement (Fig. 2). The holes were filled with soil cuttings and salt water to reduce probe contact resistance. A 1.6-cm-diameter reference electrode was driven into a hole having a diameter slightly smaller than the electrode, assuring good contact. This pilot hole was made with a conventional extended twist drill.

Three test electrodes (tunnel 1-3) were installed (Table 1). The backfill was varied to include different water, salt, organic and mineral contents. At electrodes 1 and 2, 2.1 and 2.3 kg of salt were used, amounts similar to those used at the Eielson location. Water was added to saturate the backfill for electrode 1. At electrode 2 the backfill was only moistened, and at electrode 3 the hole was filled with silt, water and 0.46 kg of salt.

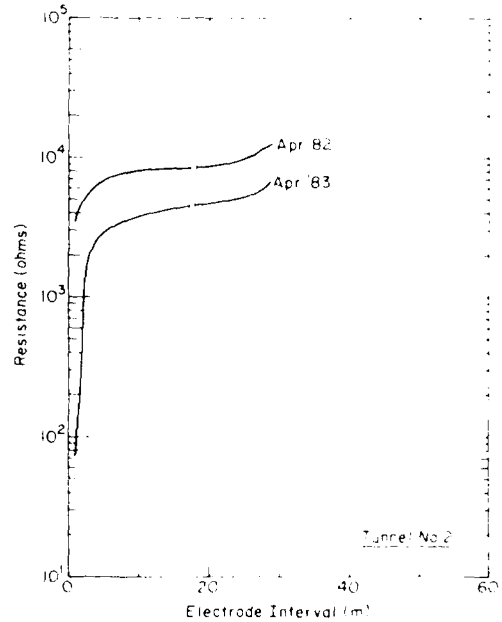


Figure 20. Resistance-to-ground curves for an electrode surrounded with backfill including salt (2.3 kg), silt and water (Tunnel 2).

Resistance to ground of all of the tunnel electrodes was quite high. Profiles obtained in April 1982 and April 1983 are shown in Figures 18-21.

Resistance of the untreated reference electrode (Fig. 18) is nearly the same for both observation periods (6700 and 7000 ohm). The other three electrodes show a systematic decrease in resistance with time. This decrease might be due to salt movement in the frozen silt, increasing the effective electrode diameter.

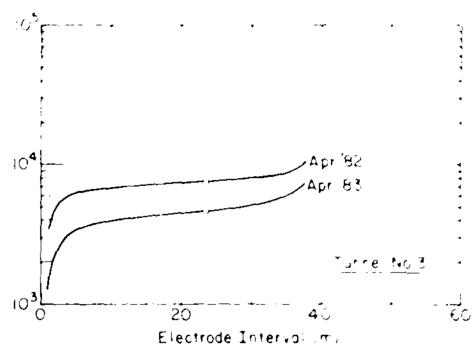


Figure 21. Resistance-to-ground curves for an electrode surrounded with backfill including salt (0.46 kg), silt and water (Tunnel 3).

DISCUSSION

Salt is extremely likely to move into the soil adjacent to the electrode backfill. The rate, however, is unknown. This rate will depend on soil properties, including grain size, degree of saturation (water and ice content), and unfrozen water content in materials below 0°C. In very fine grained frozen material (silt and clay), salt movement will most likely depend on diffusion; in coarser-grained material, salt may move by both diffusion and infiltration.

The apparent movement of salt into the surrounding material is important at grounding installations since it can reduce the resistance to ground by increasing the effective electrode diameter. Electrodes tunnel 1-3 and Wainwright 2-3 may demonstrate this effect.

The tunnel installations should most accurately reflect salt movement, since there is no other apparent explanation for decreased electrode resistance with time. Changes due to variations in temperature and moisture content should not occur at this site since this site is not subject to seasonal thaw. The ice volume of the silt exceeds the void volume normally associated with grain-to-grain contact of this material (this excess ice can be seen as small, lens-shaped masses).

One year after the tunnel electrodes were installed, the resistance values had decreased. Assuming this to be a result of salt movement, we can calculate the increase in effective electrode diameter using the procedure discussed in the methods section.

The increase in effective electrode diameter computed for the tunnel electrodes was 8.7 cm/yr at tunnel 1, 18.6 cm/yr at tunnel 2, and 7.9 cm/yr at tunnel 3. These rates are higher than Murrmann's (1973) diffusion data

would suggest, and the observed rates of 1.5-3.1 cm/yr reported by Ugolini and Anderson (1973) for material between -3° and -6°C. Our rates may be higher because our salt contents were high enough that both thaw and diffusion were probably taking place. The procedures used were also very different.

Much different rates were calculated for the Fort Wainwright site, where the material is coarser grained (sandy). Only the lower parts of the electrodes were installed in perennially frozen material. The upper electrode sections are seasonally surrounded with frozen material, which vary in seasonal water content. The drill logs indicate a very dry sandy zone above the permafrost zone. The computed increase in effective electrode diameter for two electrodes at this location, which contained permeable thawed material that could permit rapid salt movement, providing similar values of approximately 100 cm/yr at Wainwright 1 and 105 cm/yr at Wainwright 2.

CONCLUSIONS

Large seasonal variations in electrode performance occur due to variations in unfrozen water content in both thawed and frozen materials. In some situations the improvement in grounding conditions during thaw periods can be extended by the use of conductive backfill. The lower freezing point of the backfill will also reduce electrode contact resistance caused by freezing around the metallic electrodes.

The improvements based on our attempts to increase electrode performance varied greatly, depending on local conditions. The best performance was observed at the interior Alaska silt site (Eielson), where resistance to ground was reduced by approximately an order of magnitude, from 1500 to 175 ohms. The influence of the salt-treated backfill was also preserved through several thaw seasons. The modified backfill reduced electrode resistance only slightly in the colder silt at the tunnel site. Modified backfill techniques may be most useful in the subarctic and areas of seasonally frozen ground, where seasonal variations in grounding characteristics can be greatly reduced, in part through reducing contact resistance.

Several techniques were used for single electrode installation, but any method for producing a hole is acceptable. The methods discussed were selected for compatability with military operations.

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